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Detuning effect study of High-Q Mobile Phone Antennas

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Abstract—Number of frequency bands that have to be covered by smart phones, are ever increasing. This broadband coverage can be obtained either by using a low-Q antenna or a high-Q tunable antenna. This study investigates high-Q antennas performance when placed in proximity of the user. This study is carried out through measurements, using Cellular Telecommunications Industry Association (CTIA) specified head and hand phantoms. The results of the high-Q antenna are, at low as well as high frequencies, compared to the results for a low-Q antenna. The results show that detuning of low-Q antennas is more severe compared to high-Q antennas. However, the drop in efficiency is comparable for both antennas in proximity of the user.

Index Terms—High-Q antenna, low-Q antenna, propagation loss, electromagnetic reflection

I. INTRODUCTION

The development of wireless communication has been major during the last decade. The growing demand for high data rates has driven the development of Long Term Evolution (LTE). With LTE the required bands to be covered by a handheld device, are situated in the frequency range 700 MHz - 3800 MHz [1]. Such a broadband coverage, in small form factor devices, is a challenge because of fundamental limitations of antennas [2], [3]. In addition, these antennas need to be highly integrated and efficient, making the design more challenging because size, bandwidth and efficiency at a given frequency are a trade-off [4].

To cover this wide frequency range, one can either use low-Quality factor (Q) antenna with multi-resonant matching [5] - [7] or utilize a high-Q antenna that covers the broad frequency range by means of tunability [8] - [10]. The advantage of high-Q tunable antenna is that a smaller element can be used to cover the needed bandwidth, which is very attractive for handset manufacturers because antenna takes a large part of the handset volume.

A major constraint that the antenna designers have to deal with, is the user effect. The issue arises when the user either gets close to or touches the device, which disturbs the antenna near fields and thus lead to degradation in the antenna performance [11]. User has long been acknowledged to have a major impact on mobile antenna performance, as it absorbs power and detunes the center frequency of the antenna. User effects are studied in [12] and [13], where antennas of different Q are compared with respect to detuning in frequency, absorption loss and mismatch loss. These investigations are performed

only in simulations. The purpose of this paper is to study, through measurements, the robustness of high-Q antenna at the presence of a user's head and hand. Further, a comparison will be made to a similar type of antenna, but with much lower Q.

Four antenna prototypes are made; a LB low-Q, a HB low-Q, a LB high-Q and a HB high-Q antenna. Each of these prototypes are measured in three different use cases; Free Space (FS), Hand Right (HR) and Beside Head and Hand Right (BHHR). The measurements with the user are carried out for two different antenna locations on the Printed Circuit Board (PCB); top and bottom. The measurements including the user are done using the Cellular Telecommunications Industry Association (CTIA) specified Specific Anthropomorphic Mannequin (SAM) head phantom and the CTIA specified hand phantom [14].

The remainder of this paper is arranged as follows. The antennas used for the user effect study are described in Section II. In Section III the phantoms used for the measurements are presented. Section IV contains the measured results and Section V concludes the paper.

II. ANTENNAS FOR THE USER EFFECT STUDY

The geometry of the design, used to investigate user effect, is shown in Fig. 1. It is a simple Inverted L Antenna (ILA) placed at extension of the Printed Circuit Board (PCB). The PCB has the dimensions 120 mm x 55 mm. For operation at lower frequencies one LB low-Q and one LB high-Q antenna is prototyped, while for operation at higher frequencies one HB low-Q and one HB high-Q antenna is prototyped. The antenna in the figure is a LB low-Q antenna with a volume of 0.9 cc, and covers the frequency range 700 - 960 MHz. The LB high-Q antenna is attained mainly by reducing the element distance to the PCB, which ends up with a volume of 0.03 cc and covers a bandwidth of about 20 MHz. LB antennas are scaled down in size for operation at higher frequencies. The HB low-Q antenna has a volume of 0.144 cc and covers the frequency range 1710 - 2170 MHz, while the HB high-Q antenna volume is 0.012 cc and covers a bandwidth of about 60 MHz.

Matching circuit of the low-Q and high-Q antennas are depicted in Fig. 2, where it is seen that the high-Q antennas are matched using a series and a shunt inductor, while the low-Q antennas are matched utilizing a series inductor, a

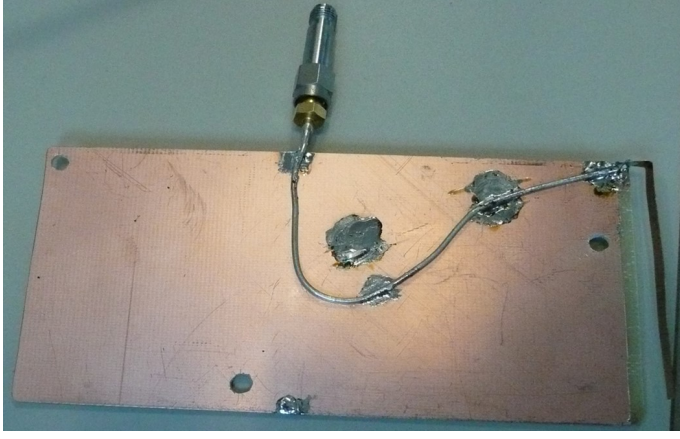


Fig. 1. PCB with LB low-Q antenna.

shunt inductor and a shunt capacitor. Commercial discrete components [15] are used for this purpose, see Fig. 2 for component values.

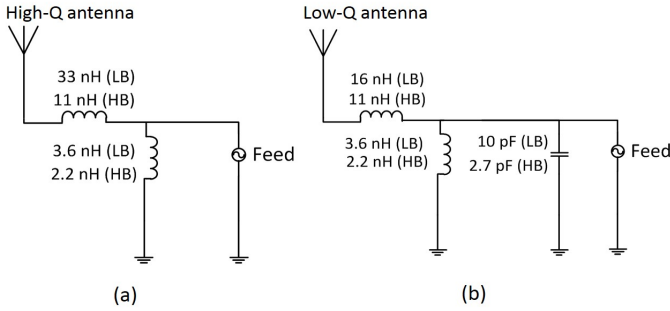


Fig. 2. Matching circuit.

Fig. 3 shows PCB together with the housing. The covers ($\epsilon_r=2.8$) are specially designed and printed to encase the PCB, making it possible to measure with head and hand. The total thickness of the mock-up, with the covers, becomes 8 mm, which is similar to the thickness of the devices available on the market today.

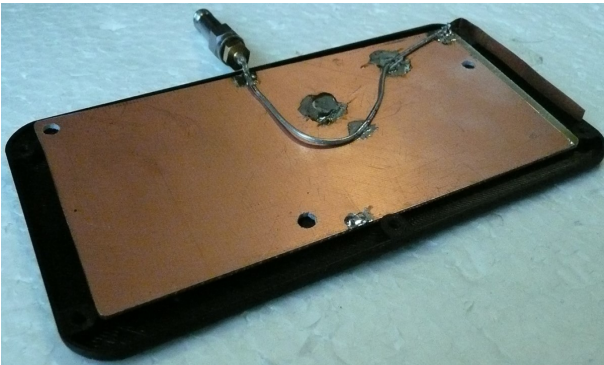


Fig. 3. Mock-up with the housing.

III. PHANTOMS FOR THE USER EFFECT STUDY

As illustrated in Fig. 4, standardized head and hand phantoms are applied for head and hand measurements. Apart from FS measurements, two other use case measurements are performed, namely HR and BHHR. However, the antennas are designed and matched for FS case. Moreover, the user measurements are carried out for two different antenna locations; top and bottom, where the mock-up is simply rotated 180 degrees for bottom location measurements. The head and hand phantoms together with the mock-up are placed in the anechoic chamber for efficiency measurements at the presence of the user, see Fig. 4.

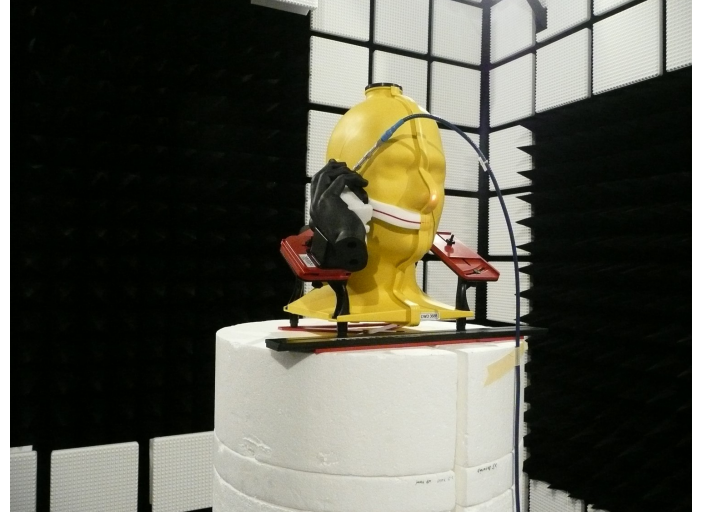


Fig. 4. Measurement setup.

IV. MEASURED RESULTS

S-parameters and impedances of each antenna are measured in three different use cases, namely FS, HR and BHHR. Fig. 5 and 6 show measured plots for the top located LB antennas, where it can be observed that high-Q antennas detune very little. Table I compares the detuning of low-Q and high-Q antennas for all measured cases. The table shows how much each antenna - either in HR or BHHR use case - shifts in frequency - at low and high $S_{11}=-6$ dB matching point - relative to FS. It can be noted that detuning of high-Q antennas is lower than 1 % in most case, which is caused by their confined fields. Low-Q antennas detune more in general compared to high-Q antennas. The problem with high-Q antennas is that even small shift in frequency can cause problems since the antennas could potentially be tuned outside the operating frequencies. However, the small detuning issue can be fixed with the help of tunable components.

Another concern, at the presence of the user, is mismatch of the antenna, because additional tunable matching circuits will be necessary for transforming the impedance back to 50 ohm. However, the measured results indicate that the mismatch is not a concern, as the antennas are matched well below $S_{11}=-6$

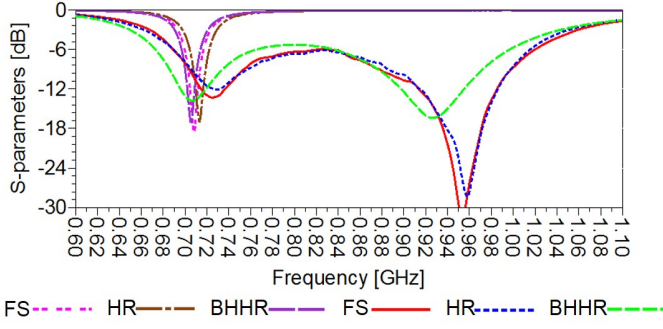


Fig. 5. Measured S-parameters of the top located LB antennas.

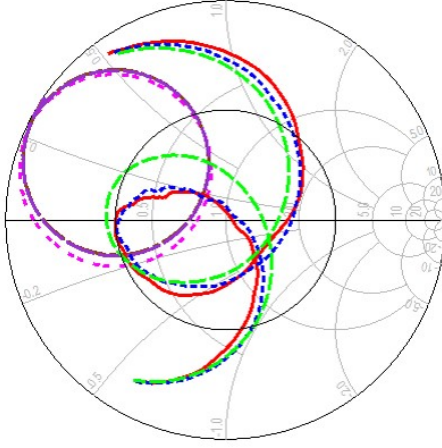


Fig. 6. Measured impedances of the top located LB antennas..

dB in all use cases. A potential mismatch issue can be solved by matching the antennas for e.g. BHHR instead of FS use case, in the design phase.

Measured efficiencies of the low-Q and high-Q antennas, in FS as well as BHHR use case, are depicted in Fig. 7. The results show that high-Q antennas have lower efficiencies at HB as well as LB. This is because as the Q of the antenna increases, its current density also increases, making it more susceptible to losses. Hence, the same equivalent series resistance of a matching component will lead to more losses due to the increased current density. Equivalently, antenna conductor with the same conductivity can lead to more loss, if the antenna Q is increased. Looking at the drop in efficiency with the user, it can be noted that high-Q antennas drop similar to low-Q antennas [16].

V. CONCLUSION

This paper has studied degradation of the antenna performance due to interaction with a user's hand and head. In general, detuning is worse for low-Q antennas. High-Q antennas exhibit less detuning due to their confined fields. The measurements show that, in FS, the total loss of a high-Q antenna is higher, which is due to the high current density

TABLE I
DETUNING RELATIVE TO FS CASE.

Config.	Use case	$S_{11} = -6$ dB point	Detuning [%]
LB high-Q top antenna	HR	low	0.6
		high	0.7
	BHHR	low	0.4
		high	0.4
LB low-Q top antenna	HR	low	0.1
		high	0.4
	BHHR	low	2.4
		high	2.3
LB high-Q bottom antenna	HR	low	0.2
		high	0.4
	BHHR	low	0.7
		high	0.8
LB low-Q bottom antenna	HR	low	4.6
		high	1.5
	BHHR	low	3.6
		high	1.7
HB high-Q top antenna	HR	low	0.3
		high	0.2
	BHHR	low	1.3
		high	1.2
HB low-Q top antenna	HR	low	1.1
		high	0.4
	BHHR	low	4.0
		high	0.4
HB high-Q bottom antenna	HR	low	0.5
		high	0.4
	BHHR	low	0.5
		high	0.2
HB low-Q bottom antenna	HR	low	1.9
		high	0.1
	BHHR	low	2.2
		high	1.4

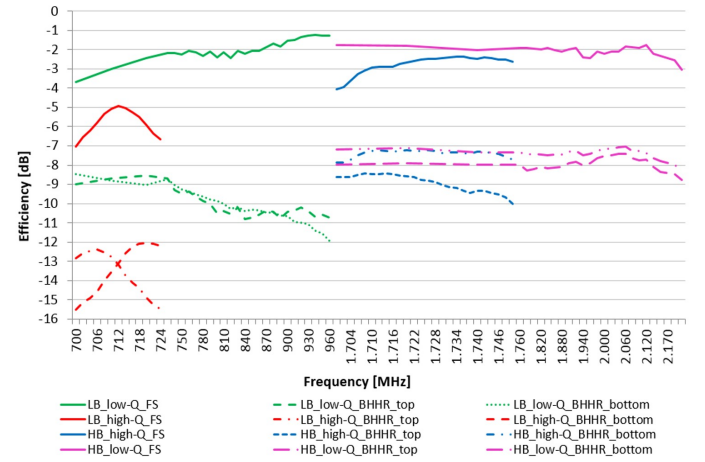


Fig. 7. Measured total efficiency.

associated with high-Q antennas. Finally, it is demonstrated through measurements that, at presence of the user, the low-Q and high-Q antennas drop in the same manner.

ACKNOWLEDGMENT

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